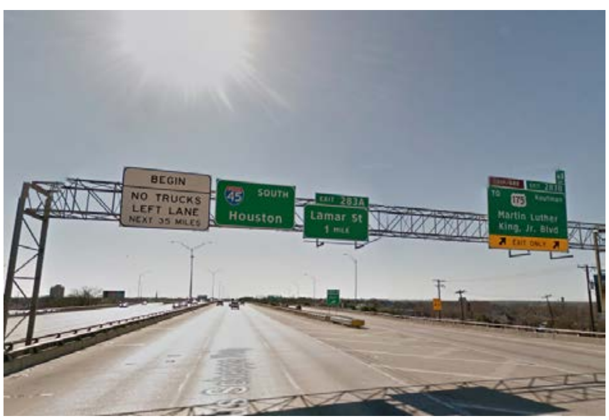
# Safety Performance of Truck Lane Restrictions in Dallas-Fort Worth

**August, 2016**



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## Introduction

This study was undertaken to evaluate the safety performance of the truck lane restrictions (TLR) that have been implemented in the North Texas region. These truck lane restrictions prohibit semi- trucks (trucks) from using left-most freeway lane, or inner lane, except in passing or emergency maneuvers. The North Central Texas Council of Governments (NCTCOG) recently presented safety findings from the October 2006 *Truck Lane Restriction Study: Final Report* and July 2009 *North Central Texas Truck Lane Restriction Expansion Traffic Study Report* [1]. However, these findings were only based on the two original pilot study sections and used very short "Before" and "After" periods. Typically a minimum time period of one-year was needed to develop any findings from crash data because of the random nature of crashes and to account for the regression to the mean bias. Thus, the Texas A&M Transportation Institute (TTI) Center for Transportation Safety (CTS) provided funding to conduct a more comprehensive Before and After safety study by expanding it to the existing TLRs and by increasing the analysis period.

[1] Available: http://nctcog.org/trans/goods/trucks/TruckLaneRestrictionExpansionStudy_June_2009_Revised_July_2009_FINAL_REPORT.pdf Accessed: August 27, 2016.

## Background

The first TLR in Texas was implemented on I-10 East freeway in Houston in September, 2000. Based on the experience and the criteria developed for the Houston TLR, NCTCOG implemented two pilot sections in Dallas-Fort Worth (DFW): I-20 in Dallas and I-30 in Fort Worth in November, 2005 which were evaluated in the October 2006 *Truck Lane Restriction Study: Final Report* [2] done by NCTCOG. The 2006 study determined that the pilot TLR sections should remain in place following the study due to the initial positive improvements in average speed, a decline in crashes, and a reduction in Nitrogen Oxide (NOx) emissions. Subsequently, a July 2009 *North Central Texas Truck Lane Restriction Expansion Traffic Study Report* [3] was done by NCTCOG in conjunction with the Dallas and Fort Worth TxDOT Districts. It recommended additional TLR sections in North Texas for consideration by TxDOT. Further analysis of the possible TLR sections was done by TTI on behalf of the Fort Worth District in 2013. The following criteria were used in that study to determine corridor feasibility for TLR implementation (a similar analysis was done by the Dallas District):[4]

- Criterion 1: Six-mile minimum length of freeway section,
- Criterion 2: Six-lane or wider freeway cross-section,
- Criterion 3: Total truck volume of at least 4 percent in the mix,
- Criterion 4: At least 5 percent of total truck traffic using the left (inside) lane, and
- Criterion 5: No left (inside) side ramps within the limits.

The TTI team determined the extent and locations of current TLR routes in DFW and statewide. Table 1 summarizes the region, number, freeway, and limits of TLR routes statewide identified early in this study. The table clearly indicates that the Dallas and Fort Worth Districts have the majority of current TLR-designated freeway sections throughout the state. Houston has four, San Antonio has three, Waco has two, and Austin and El Paso have one each. In contrast, the Dallas District has 16 and the Fort Worth District has 10.

[2] Available: http://www.nctcog.org/trans/goods/trucklane/NCTCOG_Report.pdf Accessed: August 27, 2016.

[3] Available: http://nctcog.org/trans/goods/trucks/TruckLaneRestrictionExpansionStudy_June_2009_Revised_July_2009_FINAL_REPORT.pdf Accessed: August 27, 2016.

[4] Unpublished TTI Tech Memo. Analyzing potential restricted truck lane facilities in the Fort Worth District. March 21, 2013, Texas A&M Transportation Institute to TxDOT Fort Worth District.

**Table 1. Statewide Truck Lane Restriction (TLR) Sections**

| Region | Freeway | Limits of the restriction | Miles |
|---|---|---|---|
| Houston | | | **75** |
| 1 | I-10 East | East of Downtown to Harris/Chambers County Line | 17 |
| 2 | SH 225 La Porte | East of I-610 East Loop to SH 146 | 15 |
| 3 | I-45 North | North of I-610 to Hardy Toll Road | 21 |
| 4 | US 290 | West of I-610 to Muescke Road | 22 |
| San Antonio | | | **43** |
| 1 | IH 10 | Loop 410 (east side of SA) to IH 35 | 9 |
| 2 | US 90 | IH 35 to Loop 410 (west side of SA) | 8 |
| 3 | IH 35 | Loop 1604 (northeast side of SA) to Comal/Hays County line | 26 |
| Austin | | | |
| 1 | IH 35 | Comal/Hays County line to the Williamson/Bell County line | **79** |
| Waco | | | **16** |
| 1 | IH 35 | Williamson/Bell County line to FM 2115 (south of Salado, TX) | 5 |
| 2 | IH 35 | IH 35 East/West split in Hillsboro south to FM 2063 (near Hewitt, TX) | 11 |
| Dallas | | | **161** |
| 1 | IH 20 | North Cedar Ridge Drive to IH 45 | 12 |
| 2 | IH 30 | Belt Line to SH 205 | 10 |
| 3 | US 75 | IH 635 to SH 121 south | 18 |
| 4 | IH 635 | IH 35E to Tarrant County Line | 9 |
| 5 | IH 635 | US 75 to IH 20 | 20 |
| 6 | US 175 | SH 310 to IH 20 | 9 |
| 7 | IH 35E | US 77 to IH 30 | 18 |
| 8 | LP 12 | SP 408 to SP 348 | 10 |
| 9 | SH 114 | SP 348 to Tarrant County Line | 6 |
| 10 | IH 45 | IH 30 to FM 85 | 38 |
| 11 | IH 20 | IH 45 to St. Augustine Dr. | 4 |
| 12 | IH 20 | Tarrant County Line to North Cedar Ridge Drive | 7 |
| Ft Worth | | | **67** |
| 1 | IH 30 | Collins St. (Arlington) to Hulen St. (Fort Worth) | 18 |
| 2 | IH 20 | IH 820 (West Loop) TO Dallas County Line | 6 |
| 3 | IH 35W | SH 174 to IH 30 | 12 |
| 4 | IH 820 | IH 30 to IH 35W | 11 |
| 5 | SH 121 | IH 35W to IH 820 | 6 |
| 6 | SH 360 | IH 20 to SH 183 | 9 |
| 7 | IH 30 | Hulen St. to IH 820 (West Loop) | 5 |
| El Paso | | | |
| 1 | I-10 | Zaragoza to N Mesa | **21** |

## Study Methodology

The research team initially identified 19 analysis sections where truck-lane restrictions had been implemented and 5 "control" sections where this treatment had not been implemented as shown in Table 2. Section 2 was later dropped because the TLR was never implemented due to on-going construction, Section 9 was removed due to data quality issues, and Section 15 was dropped due to the limited "after" data available. Control sections were selected with similar number of lanes and average daily traffic (ADT) as the TLR sections. Figure 1 show the TLR and control sections that were analyzed.

**Table 2. Dallas-Ft. Worth Truck Lane Restriction and Control Sections Evaluated**

| NO | DIST | HWY | LIMITS | Miles | Start Date | Before | Before Months | After | After Months |
|---|---|---|---|---|---|---|---|---|---|
| **Evaluated sections** | | | | | | | | | |
| 1 | DAL | IH 20 | North Cedar Ridge Drive to IH 45 | 12.2 | 11/1/2005 | 1/1/03-10/31/05 | 34 | 11/1/05-7/31/08 | 33 |
| ~~2~~ | ~~DAL~~ | ~~IH 30~~ | ~~Sylvan Ave to Tarrant County Line~~ | ~~12.70~~ | ~~under const.~~ | ~~NA~~ | ~~NA~~ | ~~NA~~ | ~~NA~~ |
| 3 | DAL | IH 30 | Belt Line to SH 205 | 9.83 | 9/21/2015 | 9/21/12-9/20/15 | 36 | 9/21/15-5/31/16 | 8 |
| 4 | DAL | US 75 | SH 121 south to IH 635 | 18.00 | 9/21/2015 | 9/21/12-9/20/15 | 36 | 9/21/15-5/31/16 | 8 |
| 5 | DAL | IH 635 | Tarrant County Line to IH 35E | 8.60 | 9/21/2015 | 9/21/12-9/20/15 | 36 | 9/21/15-5/31/16 | 8 |
| 6 | DAL | IH 635 | US 75 to IH 20 | 19.80 | 9/21/2015 | 9/21/12-9/20/15 | 36 | 9/21/15-5/31/16 | 8 |
| 7 | DAL | US 175 | SH 310 to IH 20 | 8.63 | 9/21/2015 | 9/21/12-9/20/15 | 36 | 9/21/15-5/31/16 | 8 |
| 8 | DAL | IH 35E | US 77 to IH 30 | 18.0 | 6/2/2015 | 6/2/14-6/1/15 | 12 | 6/2/15-5/31/16 | 12 |
| ~~9~~ | ~~DAL~~ | ~~LP 12~~ | ~~SP 348 to SP 408~~ | ~~9.90~~ | ~~10/9/2014~~ | ~~2/9/13-10/8/14~~ | ~~20~~ | ~~10/9/14-5/31/16~~ | ~~20~~ |
| 10 | DAL | SH 114 | Tarrant County Line to SP 348 | 5.62 | 9/21/2015 | 9/22/12-9/20/15 | 36 | 9/21/15-5/31/16 | 8 |
| 11 | DAL | IH 45 | IH 30 to FM 85 | 38 | 8/1/2014 | 10/1/12-7/31/14 | 22 | 8/1/14-5/31/16 | 22 |
| 12 | DAL | IH 20 | IH 45 to St. Augustine Dr. | 4.4 | 8/1/2014 | 10/1/12-7/31/14 | 22 | 8/1/14-5/31/16 | 22 |
| 13 | DAL | IH 20 | Tarrant County Line to North Cedar Ridge Drive | 6.5 | 8/1/2014 | 10/1/12-7/31/14 | 22 | 8/1/14-5/31/16 | 22 |
| 14 | FW | IH 30 | Hulen St. (Fort Worth) to Collins St. (Arlington) | 18 | 11/1/2005 | 1/1/03-10/31/05 | 34 | 11/1/05-7/31/08 | 33 |
| ~~15~~ | ~~FW~~ | ~~IH 20~~ | ~~US 180 to IH 20/IH 30 split in Parker County~~ | ~~6.1~~ | ~~3/1/2016~~ | ~~3/1/13-2/28/15~~ | ~~36~~ | ~~3/1/16-5/31/16~~ | ~~3~~ |
| 16 | FW | IH 35W | IH 30 to SH 174 | 11.7 | 1/1/2016 | 1/1/13-12/31/15 | 36 | 1/1/16-5/31/16 | 5 |
| 17 | FW | IH 820 | IH 30 to IH 35W | 11.1 | 1/1/2016 | 1/1/13-12/31/15 | 36 | 1/1/16-5/31/16 | 5 |
| 18 | FW | SH 121 | IH 35W to IH 820 | 6 | 1/1/2016 | 1/1/13-12/31/15 | 36 | 1/1/16-5/31/16 | 5 |
| 19 | FW | SH 360 | SH 183 to IH 20 | 9.1 | 1/1/2016 | 1/1/13-12/31/15 | 36 | 1/1/16-5/31/16 | 5 |
| **Control sections** | | | | | | | | | |
| 20 | DAL | SH183 | SH 161 to IH 35E | 9.2 | 9/21/2015 | 9/21/12-9/20/15 | 36 | 9/21/15-5/31/16 | 8 |
| 21 | DAL | SP408 | LP 12 to IH 20 | 4.095 | 1/1/2016 | 1/1/13-12/31/15 | 36 | 1/1/16-5/31/16 | 5 |
| 22 | FW | IH 820 | IH 35W to SH 183/SH 121 | 5.835 | 1/1/2016 | 1/1/13-12/31/15 | 36 | 1/1/16-5/31/16 | 5 |
| 23 | FW | SH 183/SH121 | IH 820 to SH 161 | 10.9 | 9/21/2015 | 9/21/12-9/20/15 | 36 | 9/21/15-5/31/16 | 8 |
| 24 | FW | SH 114 | SH 170 to SH 121 | 12.9 | 9/21/2015 | 9/22/12-9/20/15 | 36 | 9/21/15-5/31/16 | 8 |

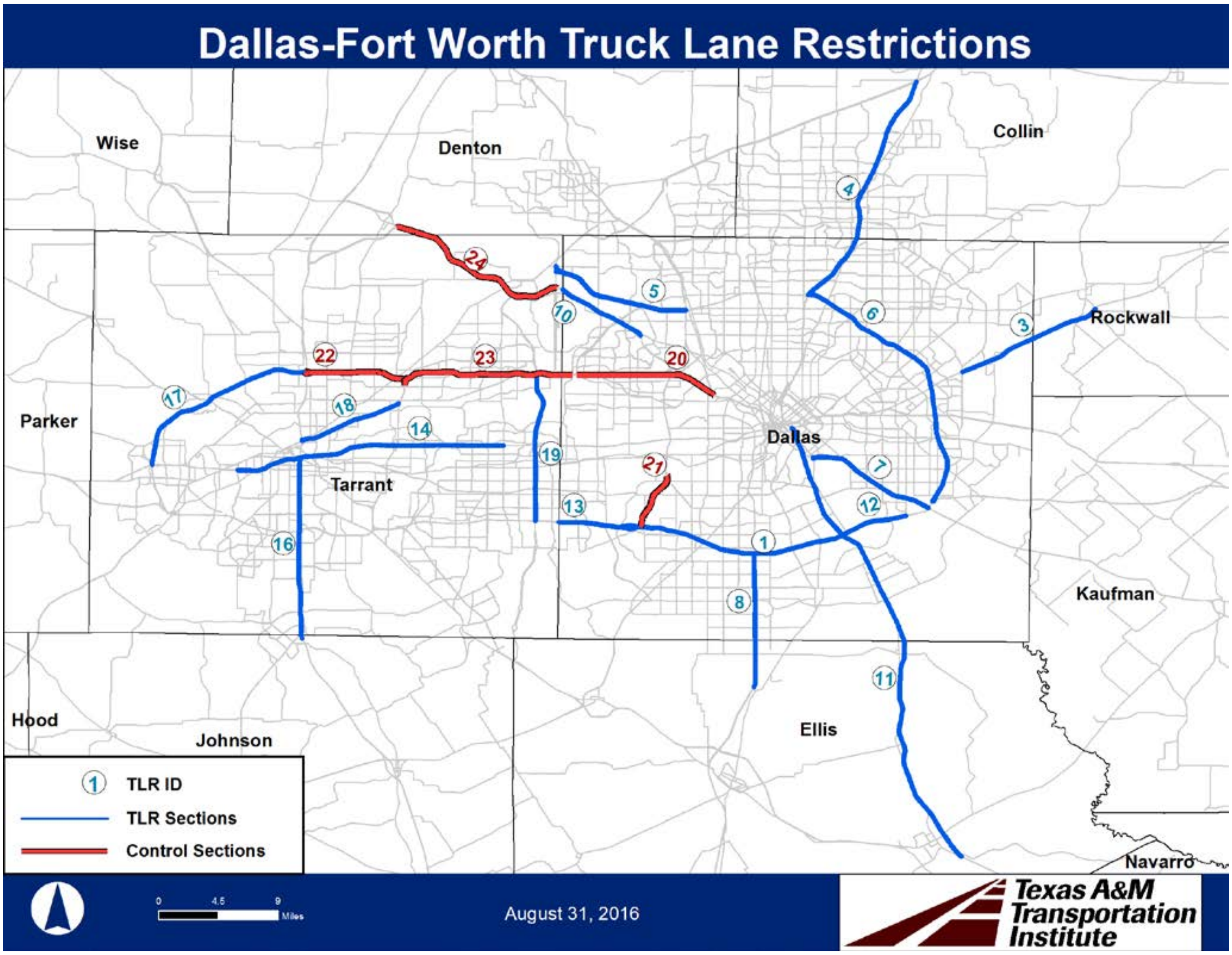


**Figure 1.TLR Sections and Control Sections Analyzed**

Using available data from TxDOT's Crash Record Information System, CRIS, crashes were reduced for each section's limits and analysis periods. However, not all crashes could be located using CRIS's internal reference system (e.g. control section, Texas reference markers, etc.) because they had not been geo-located yet. Thus, TTI developed a method to geo-locate the crashes that were missing coordinates. This helped to ensure that all available crashes were included. Table 3 shows that 14% of all crashes were located by TTI's method. This percentage ranged from 0.2% to 42% by section.

**Table 3. Crash Geolocation Summary**

| Section No. | CRIS located crashes | TTI located crashes | Total | TTI/Total |
|---|---|---|---|---|
| **1** | 1773 | 9 | 1782 | 1% |
| **3** | 505 | 62 | 567 | 11% |
| **4** | 3541 | 475 | 4016 | 12% |
| **5** | 296 | 63 | 359 | 18% |
| **6** | 3203 | 574 | 3777 | 15% |
| **7** | 282 | 164 | 446 | 37% |
| **8** | 854 | 60 | 914 | 7% |
| **10** | 163 | 92 | 255 | 36% |
| **11** | 1030 | 242 | 1272 | 19% |
| **12** | 168 | 80 | 248 | 32% |
| **13** | 569 | 159 | 728 | 22% |
| **14** | 2745 | 19 | 2764 | 1% |
| **16** | 1151 | 2 | 1153 | 0.2% |
| **17** | 688 | 15 | 703 | 2% |
| **18** | 161 | 84 | 245 | 34% |
| **19** | 1411 | 81 | 1492 | 5% |
| **20** | 619 | 442 | 1061 | 42% |
| **21** | 128 | 25 | 153 | 16% |
| **22** | 512 | 6 | 518 | 1% |
| **23** | 1218 | 601 | 1819 | 33% |
| **24** | 506 | 114 | 620 | 18% |
| **Total** | 21523 | 3369 | 24892 | 14% |

As previously stated, it was desirable to have at least 12 months of crash data in the "after" period to conduct a before-after analysis. However, ten of the analysis sections (3, 4, 5, 6, 7, 10, 16, 17, 18, and 19), had fewer than 12 months of "after" data. For these analysis sections, the Enhanced Interchange Safety Analysis Tool (ISATe) (*1*) was used to supplement the limited "after" crash data. The predicted crash frequencies from ISATe were subsequently used in the Comparison Group before-after analysis that is described in the next section of the report.

ISATe was also used to compute predicted crash frequencies for the "before" period for all TLR and control sections. The purpose of this effort was to obtain a larger basis to compare the ISATe predictions with observed crash frequencies, to assess the possible need to calibrate ISATe.

## ISATe Analysis Procedure

The ISATe analysis task required the following efforts:

1. Divide each analysis section into freeway segments according to the procedure described in the *ISATe User Manual*. Each segment was required to be homogeneous in its key characteristics such as cross-sectional widths and traffic volume. Segment break points were defined at each location where significant changes occurred or a gore point for an entrance or exit was present.
2. Enter data into the ISATe program to describe the geometric, traffic control, and volume characteristics for each segment.
3. Use ISATe to compute a predicted crash frequency for each analysis section.

The locations of segment break points, ramp gore points, and major cross-sectional changes were denoted using placemarks in Google Earth® (Figure 2) and documented in a keyhole markup language-zipped (kmz) file that contained the coordinates and labels for the placemarks. Google Earth was also used to obtain measurements of key characteristics for each segment, including the following variables:

- Cross-sectional widths (lane width, shoulder width, median width, etc.).
- Locations of longitudinal barriers.
- Horizontal curve radius and length.
- Locations of ramp gores and weaving sections.

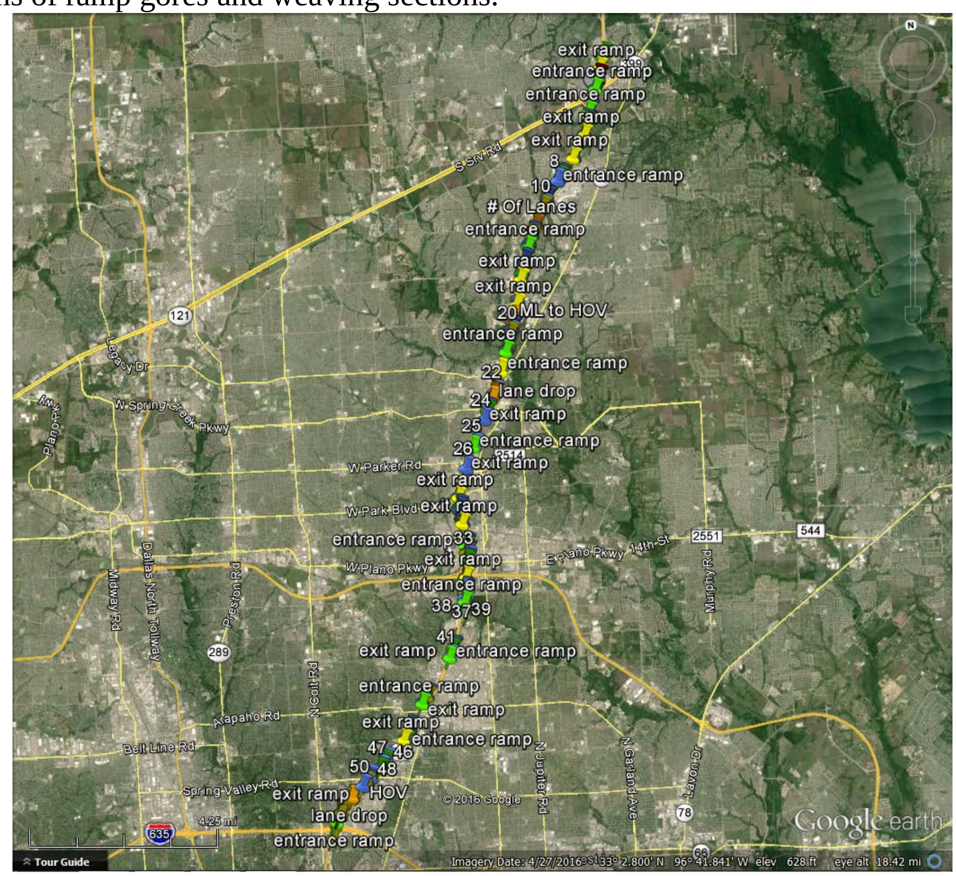


**Figure 2. Segment break points in Google Earth©**

## ISATe Results

Once the geometric data and traffic volumes were entered into ISATe, the calculation algorithms within the program were exercised. The results (using 2014 traffic volumes) are shown in Table 4. The same results are presented in Figure 3 in terms of crashes per mile per year to account for the differing lengths between sections.

**Table 4. Predicted Crash Frequencies from ISATe**

| Section | Crash Frequency, cr/yr, by Severity | | | | |
|---|---|---|---|---|---|
| | K | A | B | C | PDO |
| 3 | 1.49 | 3.50 | 24.98 | 73.50 | 239.38 |
| 4 | 5.06 | 11.30 | 81.48 | 322.49 | 964.36 |
| 5 | 0.70 | 1.79 | 12.18 | 24.94 | 86.61 |
| 6 | 4.53 | 11.03 | 71.97 | 219.22 | 697.47 |
| 7 | 0.72 | 1.82 | 11.61 | 20.50 | 78.10 |
| 10 | 0.74 | 1.79 | 12.60 | 24.64 | 77.56 |
| 12 | 0.67 | 1.75 | 10.08 | 19.25 | 73.83 |
| 13 | 1.18 | 3.16 | 21.03 | 62.36 | 195.75 |
| 16 | 2.00 | 5.48 | 38.39 | 132.36 | 420.57 |
| 17 | 1.29 | 3.43 | 23.29 | 53.34 | 180.78 |
| 18 | 0.88 | 2.32 | 16.02 | 43.78 | 141.65 |
| 19 | 2.31 | 5.68 | 39.67 | 150.79 | 510.22 |
| 20 | 1.63 | 4.42 | 30.49 | 101.11 | 316.93 |
| 21 | 0.52 | 1.34 | 8.59 | 20.02 | 65.68 |
| 22 | 0.85 | 2.38 | 13.76 | 50.01 | 164.97 |
| 23 | 2.15 | 5.99 | 36.50 | 126.08 | 435.49 |
| 24 | 1.46 | 3.92 | 23.53 | 61.07 | 209.32 |
| **Total** | 28.16 | 71.12 | 476.16 | 1505.47 | 4858.68 |

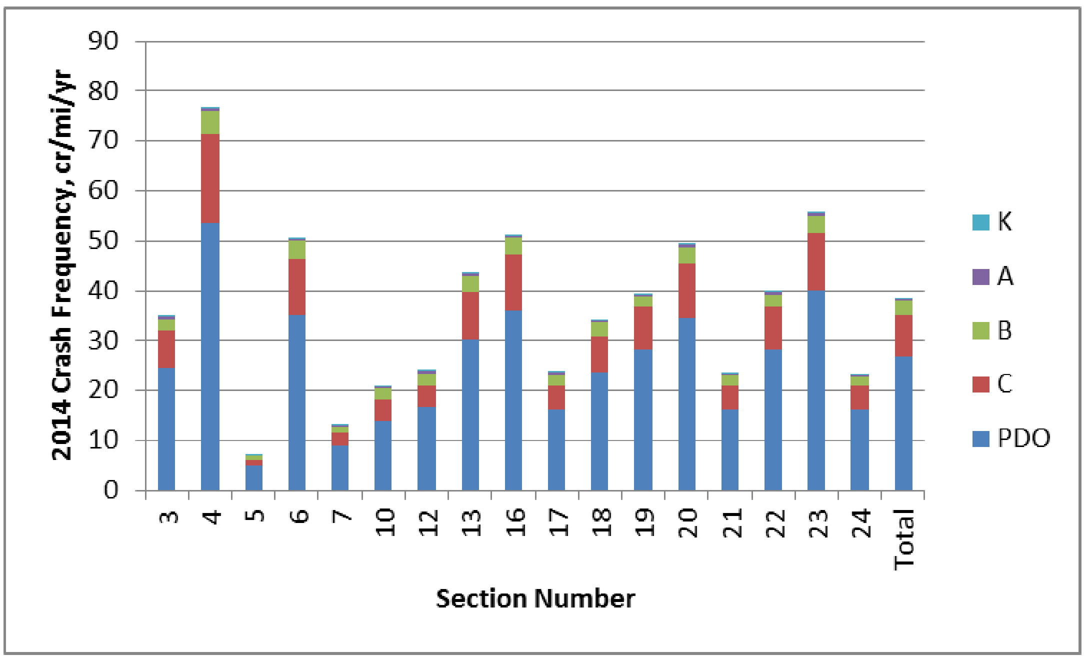


**Figure 3. Predicted Crash Frequencies per Mile from ISATe**

The distribution of crashes across the severity categories was typical for freeway facilities. Further inspection revealed that the bulk of the crashes were categorized as rear-end, sideswipe, or fixed-object, consistent with expectations for crashes on freeway facilities.

## ISATe Calibration

The HSM freeway crash prediction models were calibrated using data from the States of Washington, California, and Maine (*3*). To examine the applicability of ISATe to the freeway system in DFW, the research team compared the predicted crash frequencies in Table 4 with observed crash frequencies in the year 2014. The "before" period for sections 12 and 13 ended before the end of 2014, so both the predicted and observed crash frequencies for that year were adjusted downward accordingly. The crash frequencies for severity categories, K, A, B, and C were combined to obtain a F+I (fatal-and-injury) crash frequency for each section. A comparison of the predicted and observed crash frequencies is shown in Table 5. The same results are presented in Figure 4 (for F+I crashes) and Figure 5 (for PDO crashes) in terms of crashes per mile per year to account for the differing lengths between sections. The following observations are apparent:

- On a section-by-section basis, the ISATe-predicted values differed from the observed values (which represent a sum of CRIS and the TTI geo-located crashes).
- For F+I crashes, the ISATe prediction agreed closely with observed crash counts. The difference between the two was less than five percent (and less than one percent in an expanded analysis including the years 2012 and 2013 when available).
- ISATe predicted roughly double the number of PDO crashes that were actually observed.
- If the geo-located crashes had not been included in the analysis efforts, ISATe would have appeared to have been over-predicting crashes by a larger margin.

Table 5. Comparison of Predicted and Observed Crash Frequencies

| Section | F+I Crash Frequency, cr/yr | | PDO Crash Frequency, cr/yr | |
|---|---|---|---|---|
| | **Predicted** | **Observed** | **Predicted** | **Observed** |
| 3 | 103.47 | 54 | 239.38 | 92 |
| 4 | 420.33 | 450 | 964.36 | 561 |
| 5 | 39.61 | 31 | 86.61 | 37 |
| 6 | 306.76 | 414 | 697.47 | 511 |
| 7 | 34.66 | 30 | 78.10 | 52 |
| 10 | 39.78 | 38 | 77.56 | 29 |
| 12 | 18.52 | 26 | 43.07 | 36 |
| 13 | 51.18 | 62 | 114.19 | 113 |
| 16 | 178.22 | 135 | 420.57 | 159 |
| 17 | 81.35 | 64 | 180.78 | 98 |
| 18 | 62.99 | 27 | 141.65 | 36 |
| 19 | 198.44 | 185 | 510.22 | 193 |
| 20 | 137.65 | 117 | 316.93 | 96 |
| 21 | 30.47 | 19 | 65.68 | 18 |
| 22 | 67.00 | 40 | 164.97 | 69 |
| 23 | 170.72 | 194 | 435.49 | 256 |
| 24 | 89.98 | 54 | 209.32 | 80 |
| **Total** | 2031.12 | 1940 | 4746.35 | 2436 |

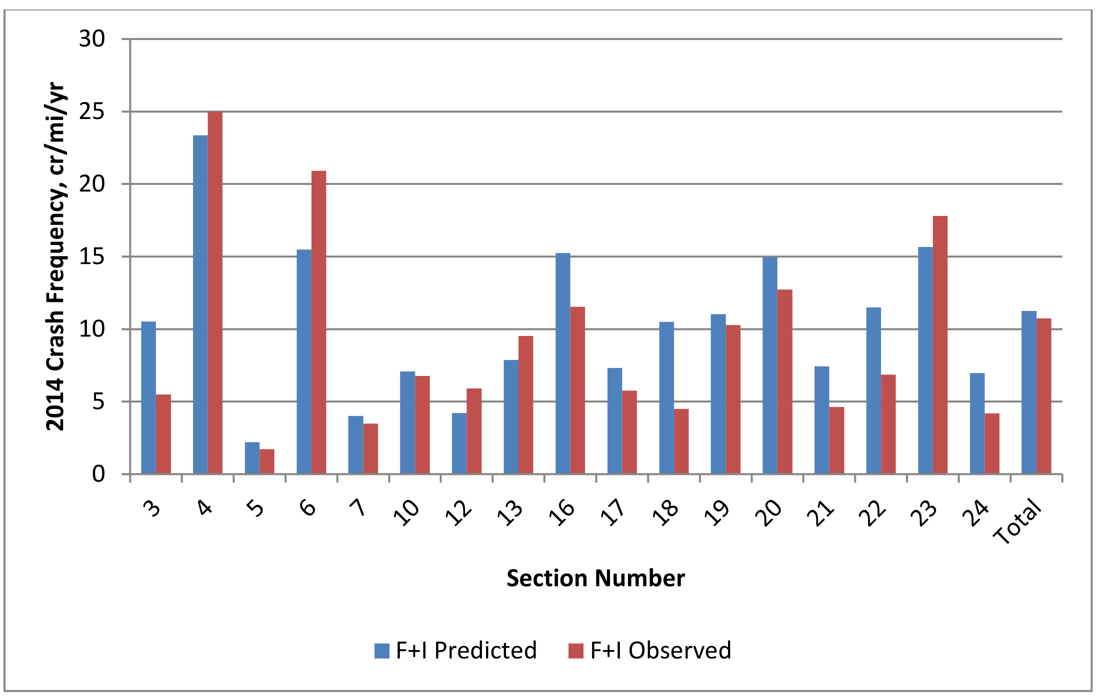


**Figure 4. Predicted and Observed F+I Crash Frequencies per Mile**

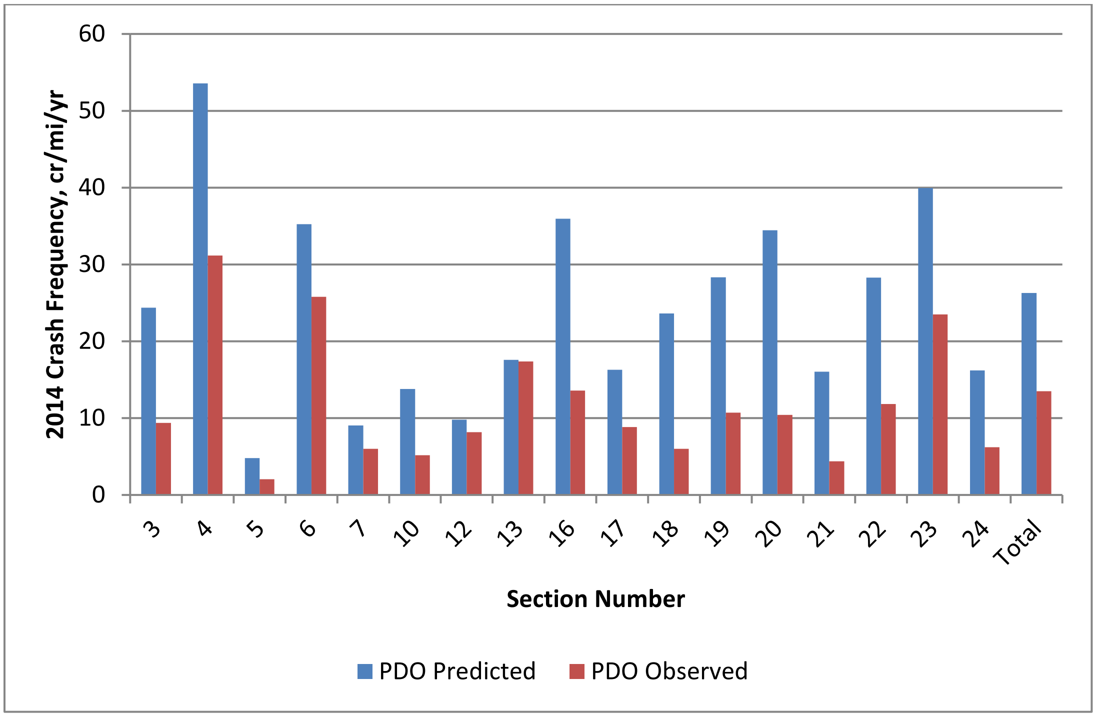


**Figure 5. Predicted and Observed PDO Crash Frequencies per Mile**

The large difference in predicted and observed PDO crash frequency was likely due to issues with reporting thresholds and practices. As explained by Bonneson et al. (*3*):

> Differences in crash reporting threshold among agencies can introduce uncertainty in crash data analysis and regional comparison of crash trends. A majority of the crashes that often go unreported (or, if reported, not filed by the agency) were those identified as "property-damage-only." In contrast, severe crashes (i.e., those crashes with an injury or fatality) tend to be more consistently reported across jurisdictions. Thus, safety relationships tend to be more transferrable among jurisdictions when they were developed using only severe crash data.

For the purpose of the truck-lane restriction analysis documented in this report, the default ISATe calibration and the underlying HSM models were adequate for the purpose of examining F+I crashes. However, a comparison of PDO crashes would require calibration of the ISATe program. Based on the available project resources, the research team decided to proceed only with a comparison of F+I crashes.

## Before-After Results

Observational before-after studies were helpful in estimating the safety effectiveness for a particular countermeasure. Two different before-after studies were used in this study: 1) Comparison group method, and 2) Empirical Bayes (EB) method.

### Comparison Group Method

Before-after study with comparison group study used an untreated comparison group of sites (control sites) similar to the treated ones to account for changes in crashes. The control site selection considers similar types of geometric feature and AADT amount. The comparison group was used to calculate the ratio of observed crash frequency in the after period to that in the before period. The common practice of selecting control sites in terms of geometric and operational characteristics was to take the sites from the same jurisdiction, which was not always possible *(5)*. This method did not account for regression-to-the-mean unless treatment and comparison sites were also matched based on the observed crash frequency in the before period. The calculation method of this current followed the steps used in Hauer's *(6)* study.

*Step 1: Determining Sample Odds Ratio*

Hauer proposes on using a sequence of sample odds ratios to quantitatively assess the suitability criteria to determine candidate control site. Control sites with odds ratio closer to 1 was ideal for candidate control sites. For this study, the research team selected five control sites for preliminary investigation. The final groups were selected based on the group specific odds ratio values.

$$Sample\ Odds\ Ratio = \frac{\frac{Treatment_b \times Control_a}{Treatment_a \times Control_b}}{1 + \frac{1}{Treatment_a} + \frac{1}{Control_b}} \qquad (1)$$

Where:

$Treatment_b$ = total crashes for the treatment group in before years
$Treatment_a$ = total crashes for the treatment group in after years
$Control_b$ = total crashes for the control group in before years
$Control_a$ = total crashes for the control group in after years

Table 6 lists the odds ratio of the final selected groups. For the control sites with less than one year of after year data, ISATe predicted values are used for calculation.

**Table 6. Odds ratio of the selected groups**

| Group | Treatment Sites | Control Sites | Odds Ratio |
|---|---|---|---|
| Group 1 | Section05 | Section20 | 0.915 |
| Group 2 | Section16 | Section21 | 0.987 |
| Group 3 | Section19 | Section22 | 0.975 |
| Group 4 | Section03 | Section23 | 1.727 |
| Group 5 | Section10 | Section24 | 0.879 |

*Step 2: Evaluate the expected values*

The expected number of crashes for the treatment group that would have occurred in the after period without treatment ($N_{expected,\ \ t,\ \ a}$) was estimated from the following equation:

$$N_{expected,\ \ t,\ \ a} = N_{observed,\ \ t,\ \ b} \times \frac{N_{observed,\ \ c,\ \ a}}{N_{observed,\ \ c,\ \ b}} \tag{2}$$

Where:

$N_{observed,\ \ t,\ \ b}$= the observed number of crashes in the before years in the treatment group $N_{observed,\ \ t,\ \ b}$= the observed number of crashes in the after years in the treatment group $N_{observed,\ \ c,\ \ b}$ = the observed number of crashes in the before years in the control group $N_{observed,\ \ c,\ \ a}$ = the observed number of crashes in the after years in the control group

The variance of $N_{expected,\ \ t,\ \ a}$ can be calculated as:

$$Var(N_{expected,\ \ t,\ \ a}) = {N_{expected,\ \ t,\ \ a}}^2 \times \left(\frac{1}{N_{observed,\ \ t,\ \ b}} + \frac{1}{N_{observed,\ \ c,\ \ b}} + \frac{1}{N_{observed,\ \ c,\ \ a}}\right) \tag{3}$$

*Step 3: Evaluate the CMF and variance of CMF:*

The CMF and its variance can be calculated from the following equations:

$$CMF = \frac{\dfrac{N_{observed,\ \ t,\ \ a}}{N_{expected,\ \ t,\ \ a}}}{1 + \dfrac{Var(N_{expected,\ \ t,\ \ a})}{{N_{expected,\ \ t,\ \ a}}^2}} \tag{4}$$

$$Var(CMF) = CMF^2 \frac{\dfrac{1}{N_{observed,\ \ t,\ \ a}} + \dfrac{Var(N_{expected,\ \ t,\ \ a})}{{N_{expected,\ \ t,\ \ a}}^2}}{\left[1 + \dfrac{Var(N_{expected,\ \ t,\ \ a})}{{N_{expected,\ \ t,\ \ a}}^2}\right]^2} \tag{5}$$

Table 7 lists the values of site specific CMF, standard deviations, and 95% confidence interval (CI) of the CMF from this method. The CMF values range from 0.66 to 1.61 for fatal and injury (KABC) crashes. Sixty percent of the sites show positive safety effectiveness. However, because 1.0 was within the range of the 95% confidence interval, it cannot be concluded that TLRs has a positive safety effect.

**Table 7. CMF and variance of CMF values for the treatment sites using comparison group method (for Fatal and Injury crashes)**

| Sites | $CMF$ | $Var(CMF)$ | $sd(CMF)$ | $95\%\ CI\ of\ CMF$ |
|---|---|---|---|---|
| Section05 | 1.61 | 0.12 | 0.3489 | (0.92, 2.29) |
| Section16 | 0.66 | 0.04 | 0.1921 | (0.28, 1.03) |
| Section19 | 0.86 | 0.03 | 0.1693 | (0.53, 1.2) |
| Section03 | 1.27 | 0.06 | 0.2482 | (0.78, 1.76) |
| Section10 | 0.80 | 0.04 | 0.2118 | (0.39, 1.22) |

## Empirical Bayes (EB) Method

The objective of the Empirical Bayes methodology was to more precisely estimate the number of crashes that would have occurred at an individual treated site in the after period had a treatment not been implemented. This method accounts for the effect of regression-to-the-mean, changes in traffic volume, and other potential changes in the roadway features during the before and after time periods. In accounting for regression-to-the-mean, the number of crashes expected in the before period without the treatment ($N_{predicted,\ t,\ b}$) was a weighted average of information from two sources *(1):*

- The number of crashes observed in the before period at the treated sites ($N_{observed,\ t,\ b}$).
- The number of crashes predicted at the treated sites based on reference sites with similar traffic and physical characteristics ($N_{predicted,\ t,\ b}$).

An SPF was a statistical model that predicts the mean crash frequency for similar locations with the same characteristics. These characteristics typically include traffic volume and may include other variables such as traffic control and geometric characteristics. This SPF was used to derive the second source of information for the empirical Bayes estimation- the number of crashes predicted at treated sites based on sites with similar operational and geometric characteristics ($N_{predicted,\ t,\ b}$). The calculation method of this current followed the steps used in Hauer's study *(6).*

*Step 1: Evaluate the predictive values*

The predictive models for urban freeway segments can be presented in the following equation:

$$N_{predicted,\ t,\ b} = C_L \times (N_{uf,\ m}) \tag{6}$$

Where:

$N_{predicted,\ t,\ b}$ = predicted crashes (crashes/year)

$C_L$= Calibration factor (considered as 1 in this study)

$\boldsymbol{N_{uf,\ m}}$= base crash frequency in urban freeways with 'm' lanes (crashes/year)

The SPFs used in this study are based on Bonneson and Pratt study *(7).*

The base model for urban freeway with six lanes:

$$N_{uf,\ 6} = (N_{mv,\ 6} + N_{sv,\ 6} + N_{ext,\ 6} + N_{ent,\ 6}) \times f_6 \tag{7}$$

Where:

$N_{uf,\ 6}$= base fatal and injury crash frequency in urban freeways with six lanes (crashes/year)

$N_{mv,\ 6}$= multiple vehicle non-ramp fatal and injury crash frequency in urban six-lane freeways (crashes/year)

$N_{sv,\ 6}$= single vehicle non-ramp fatal and injury crash frequency in urban six-lane freeways

(crashes/year)

$N_{ext,\ 6}$= exit ramp fatal and injury crash frequency in urban six-lane freeways (crashes/year)

$N_{ent,\ 6}$= entrance vehicle fatal and injury crash frequency in urban six-lane freeways (crashes/year)

$f_6$= local calibration factor

Here:

$$N_{mv,\ 6} = 0.00352 \times (0.001 \times AADT)^{1.55} \times L \tag{8}$$

$$N_{sv,\ 6} = 0.119 \times (0.001 \times AADT)^{0.646} \times L \tag{9}$$

$$N_{ent,\ 6} = 0.00532 \times (AADT/15000)^{1.33} \times n_{ent} \tag{10}$$

$$N_{ext,\ 6} = 0.00064 \times (AADT/15000)^{1.68} \times n_{ext} \tag{11}$$

Where:

$AADT$ = Annual Average Daily Traffic (vpd)

L= Length

$n_{ent}$= number of entrance ramps

$n_{ext}$= number of exit ramps

The base model for urban freeway with eight lanes:

$$N_{uf,\ 8} = (N_{mv,\ 8} + N_{sv,\ 8} + N_{ext,\ 8} + N_{ent,\ 8}) \times f_8 \tag{12}$$

Where:

$N_{uf,\ 8}$= base fatal and injury crash frequency in urban freeways with eight lanes (crashes/year)

$N_{mv,\ 8}$= multiple vehicle non-ramp fatal and injury crash frequency in urban eight-lane freeways (crashes/year)

$N_{sv,\ 8}$= single vehicle non-ramp fatal and injury crash frequency in urban eight-lane freeways (crashes/year)

$N_{ext,\ 8}$= exit ramp fatal and injury crash frequency in urban eight-lane freeways (crashes/year)

$N_{ent,\ 8}$= entrance vehicle fatal and injury crash frequency in urban eight-lane freeways (crashes/year)

$f_8$= local calibration factor

Here:

$$N_{mv,\ 8} = 0.00289 \times (0.001 \times AADT)^{1.55} \times L \tag{13}$$

$$N_{sv,\ 8} = 0.113 \times (0.001 \times AADT)^{0.646} \times L \tag{14}$$

$$N_{ent,\ 8} = 0.00199 \times (AADT/15000)^{1.33} \times n_{ent} \tag{15}$$

$$N_{ext,\ 8} = 0.000482 \times (AADT/15000)^{1.68} \times n_{ext} \tag{16}$$

Where:

$AADT$ = Annual Average Daily Traffic (vpd)

L= Length

$n_{ent}$= number of entrance ramps

$n_{ext}$= number of exit ramps

*Step 2: Evaluate the expected values*

The empirical Bayes estimate of the expected number of crashes without treatment, $N_{expected,\ t,\ b}$, was computed from the following equation:

$$N_{expected,\ t,\ b} = w \times N_{predicted,\ t,\ b} + (1 - w) \times N_{observed,\ t,\ b} \tag{17}$$

$$w = \frac{1}{1 + k \times \sum_{\substack{all\ study \\ years}} N_{predicted}} \tag{18}$$

Where:

$w$ = weighted adjustment to be placed on the predictive model estimate; and

$k$ = overdispersion parameter of the associated SPF used to estimate $N_{predicted}$

It is important to note that with the increment of over dispersion parameter, the weighted adjustment factor decreases; thus, more emphasis is placed on the observed/reported crashes rather than the SPF predicted crash frequency.

The adjusted value of the empirical Bayes estimate, $N_{expected,\ t,\ a}$, is the expected number of crashes in the after period without treatment and is calculated from the following equation:

$$N_{expected,\ t,\ a} = N_{expected,\ t,\ b} \times \frac{N_{predicted,\ t,\ a}}{N_{predicted,\ t,\ b}} \tag{19}$$

The variance of $N_{expected,\ t,\ a}$:

$$Var(N_{expected,\ t,\ a}) = N_{expected,\ t,\ a} \times \frac{N_{predicted,\ t,\ a}}{N_{predicted,\ t,\ b}} \times (1 - w) \tag{20}$$

*Step 3: Evaluate the CMF and variance of CMF:*
The CMF and its variance can be calculated from the following equations:

$$CMF = \frac{\frac{N_{observed,\ t,\ a}}{N_{expected,\ t,\ a}}}{1 + \frac{Var(N_{expected,\ t,\ a})}{N_{expected,\ t,\ a}{}^2}} \tag{21}$$

$$Var(CMF) = CMF^2 \frac{\frac{1}{N_{observed,\ t,\ a}} + \frac{Var(N_{expected,\ t,\ a})}{N_{expected,\ t,\ a}{}^2}}{\left[1 + \frac{Var(N_{expected,\ t,\ a})}{N_{expected,\ t,\ a}{}^2}\right]^2} \tag{22}$$

Table 8 lists the values of site specific CMF, standard deviations, and 95% confidence interval (CI) of the CMF from this method. For fatal and injury crashes, four of the sections show positive safety effectiveness (from Table 8). For fatal and injury crashes, four of the TLR sections show positive safety effectiveness. Out of four of those sections, two of them do not contain 1.0 in the 95% confidence interval, which suggests that these two TLR sections had a positive safety effect. Based on the nature of the countermeasure however, it was also required to evaluate the CMFs for large truck involved crashes. For fatal and injury crashes, ten of the sections show positive safety effectiveness (from Table 9). For fatal and injury crashes that involved large trucks, ten of the TLR sections show positive safety effectiveness. While considering the 95% confidence interval, only two sections show positive safety effectiveness.

**Table 8. CMF and 95% CI of the CMF values for the treatment sites using EB method (Fatal and Injury Crashes)**

| **Sites** | $CMF$ | $sd(CMF)$ | $95\%\ CI\ of\ CMF$ |
|---|---|---|---|
| Section01 | 0.74 | 0.08666 | (0.57, 0.91) |
| Section03 | 1.04 | 0.17338 | (0.7, 1.38) |
| Section04 | 1.64 | 0.09919 | (1.45, 1.83) |
| Section05 | 1.86 | 0.33785 | (1.2, 2.52) |
| Section06 | 1.3 | 0.07635 | (1.15, 1.45) |
| Section07 | 1.79 | 0.30593 | (1.19, 2.39) |
| Section08 | 1.33 | 0.13798 | (1.06, 1.6) |
| Section10 | 1.29 | 0.27163 | (0.76, 1.82) |
| Section11 | 1.11 | 0.13033 | (0.86, 1.37) |
| Section12 | 1.35 | 0.34364 | (0.67, 2.02) |
| Section13 | 1.01 | 0.14803 | (0.72, 1.3) |
| Section14 | 0.64 | 0.06079 | (0.52, 0.76) |
| Section16 | 1.34 | 0.13915 | (1.06, 1.61) |
| Section17 | 1.54 | 0.20688 | (1.13, 1.94) |
| Section18 | 0.77 | 0.17383 | (0.43, 1.11) |
| Section19 | 0.98 | 0.08726 | (0.81, 1.15) |

**Table 9. CMF and 95% CI of the CMF values for the treatment sites using EB method (Large Truck involved Fatal and Injury Crashes)**

| Sites | $CMF$ | $sd(CMF)$ | $95\%\ CI\ of\ CMF$ |
|---|---|---|---|
| Section01 | 0.67 | 0.17161 | (0.33, 1.00) |
| Section03 | 0.71 | 0.30492 | (0.11, 1.31) |
| Section04 | 1.4 | 0.38807 | (0.64, 2.16) |
| Section05 | 0.48 | 0.33165 | (0, 1.13) |
| Section06 | 1.65 | 0.38662 | (0.89, 2.41) |
| Section07 | 0.72 | 0.44274 | (0, 1.59) |
| Section08 | 1.37 | 0.43374 | (0.52, 2.22) |
| Section10 | 0.6 | 0.36854 | (0, 1.33) |
| Section11 | 1.24 | 0.42946 | (0.4, 2.08) |
| Section12 | 1.11 | 0.53473 | (0.06, 2.15) |
| Section13 | 1.04 | 0.43539 | (0.19, 1.89) |
| Section14 | 0.61 | 0.23357 | (0.15, 1.07) |
| Section16 | 0.44 | 0.18893 | (0.07, 0.81) |
| Section17 | 0.4 | 0.28137 | (0, 0.95) |
| Section18 | 0.44 | 0.30454 | (0, 1.04) |
| Section19 | 0.63 | 0.32743 | (0, 1.28) |

Table 10 lists the aggregated CMF and 95% of CMF by combining the sections into two broader facility types: 1) six-lane roadways, 2) eight-lane roadways. For all fatal and injury crashes, the CMF for both six-lane and eight-lane roadways were greater than 1. For large truck involved fatal and injury crashes, the CMF of six-lane roadways was 0.68. It should be noted that large truck related crashes were only 5% and 7% of the F+I crashes for six-lane roadways and eight-lane roadways, respectively.

**Table 10. CMF and 95% CI of the CMF values for six-lane and eight-lane roadways**

| Sites | $CMF$ | $sd(CMF)$ | $95\%\ CI\ of\ CMF$ |
|---|---|---|---|
| **All Fatal and Injury Crashes** | | | |
| Six-Lane Roadways | 1.05 | 0.13339 | (0.79, 1.31) |
| Eight-lane Roadways | 1.32 | 0.11915 | (1.08, 1.55) |
| **Large Truck Involved Fatal and Injury Crashes** | | | |
| Six-lane Roadways | 0.68 | 0.32240 | (0.05, 1.28) |
| Eight-lane Roadways | 1.17 | 0.36623 | (0.45, 1.89) |

## Conclusion

This study was undertaken to evaluate the safety performance of the truck lane restrictions that have been implemented in the North Texas region. The research team analyzed 16 TLR sections and 5 "control" sections where this treatment had not been implemented. Overall, TLRs show a positive safety effectiveness for large truck involved fatal and injury crashes for six-lane roadways, which is the majority of roadways in most urban areas including Dallas-Ft. Worth.

The finding from the Comparison Group analysis was:

- Sixty percent of the sites show positive safety effectiveness. However, because 1.0 was within the range of the 95% confidence interval, it cannot be concluded that TLRs has a positive safety effect.

The findings from the Empirical Bayes analysis were:

- For fatal and injury crashes, four of the TLR sections show positive safety effectiveness. Out of four of those sections, two of them do not contain 1.0 in the 95% confidence interval, which suggests that these two TLR sections had a positive safety effect.
- For fatal and injury crashes that involved large trucks, ten of the TLR sections show positive safety effectiveness. While considering the 95% confidence interval, only two sections show positive safety effectiveness.
- Overall, TLRs show a positive safety effectiveness for large truck involved fatal and injury crashes for six-lane roadways. It should be noted that large truck related crashes were only 5% of these F+I crashes.
- Overall, TLRs show no positive safety effectiveness for eight-lane roadways for large truck involved fatal and injury crashes. It should be noted that large truck related crashes were only 7% of these F+I crashes.

It's also worth noting that although large truck related crashes are not frequent, they tend to have higher societal impacts and costs, especially in congested urban areas. Higher costs may be associated with more injuries because they tend to be more severe crashes, have longer durations (which may induce more secondary crashes), more emissions, more vehicular and possible infrastructure damage, lost cargo costs, higher value of time for truckers, etc.

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